Advanced imaging in interventional cardiology: mixed reality to optimize preprocedural planning and intraprocedural monitoring

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Introduction Interventional cardiology is a rapidly evolving field, fueled by the technological development in devices and procedures. Advancements in imaging technologies have played a key role in facilitating the planning and monitoring of complex coronary, structural, and peripheral interventions. However, as the complexity of interventions increases, there is a need now for new imaging solutions to answer emerging clinical problems.

Mixed reality (MR) imaging is an emerging advanced imaging technique, whereby virtual computer-generated 3-dimensional (3D) models are added onto patient-specific images acquired from either echocardiography, computed tomography (CT) or magnetic resonance imaging (MRI). Mixed reality imaging can offer new solutions to complex interventional problems.

The aim of this report is to describe novel 3D imaging techniques with mixed reality enhancement and to demonstrate how these can be used to facilitate and optimize preprocedural planning and intraprocedural monitoring of coronary and structural interventions.

Technologies for creating 3D models and simulations are invaluable in planning and monitoring treatments. Mixed reality is characterized by great versatility, allowing views from different perspectives, depending on the physician's needs.

Methods **Mixed reality imaging** Mixed reality imaging combines imaging data acquired from patients with computer-generated images to create 3D holographic images. These 3D images are then incorporated into mixed reality systems consisting of cameras, a display, and several sensors. These systems enable physicians to interact with the mixed reality 3D images in real-time. The camera tracks the user's movements in relation to virtual objects, whilst a head-mounted display allows users to observe these virtual objects in the physical world. The potential utility of MR imaging can be enhanced by combining advanced imagining with artificial intelligence technologies. In the future, a key advantage of current artificial intelligence technologies is that they can significantly shorten the time required to create, process and subsequently display complex MR images compared with conventional 3D reconstructions from echocardiography, CT, or MRI imaging. This faster processing can be harnessed to provide an enhanced visualization and quantitative feedback in real-time to guide preprocedural planning as well as to monitor complex interventions intraprocedurally.

Using mixed reality imaging for preprocedural planning and intraprocedural monitoring Mixed reality imaging is versatile and can be adapted according to the underlying anatomy and intervention being performed. The ability to overlay computer-generated 3D models on top of patient-specific imaging can enable physicians to understand the often-complex geometric interactions between anatomy and intended device. This can provide a more complete understanding of both the potential impact of the intervention as well as assisting in selection of the device and procedural technique (Supplementary materials, *Figure S1A–S1E*).

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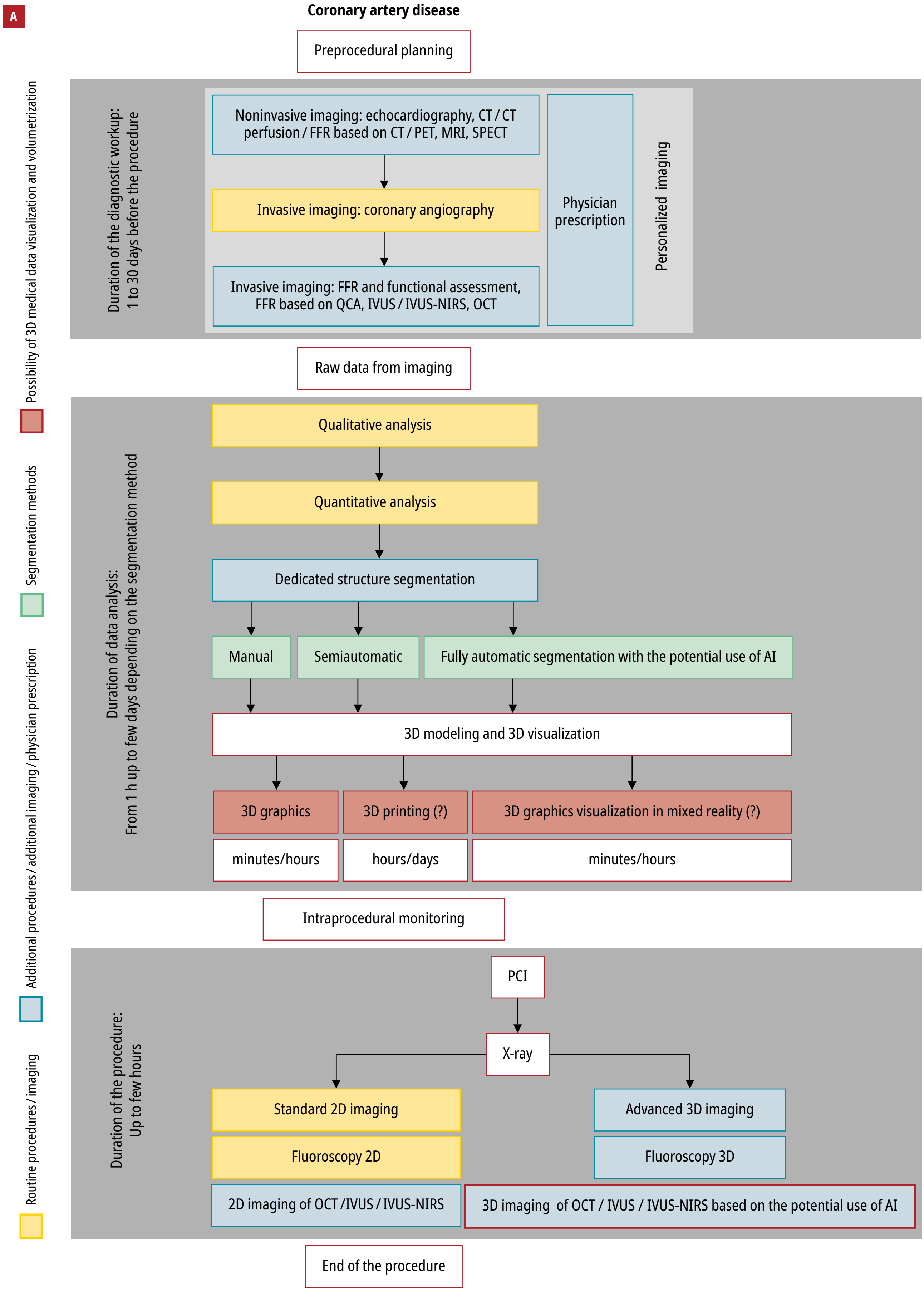
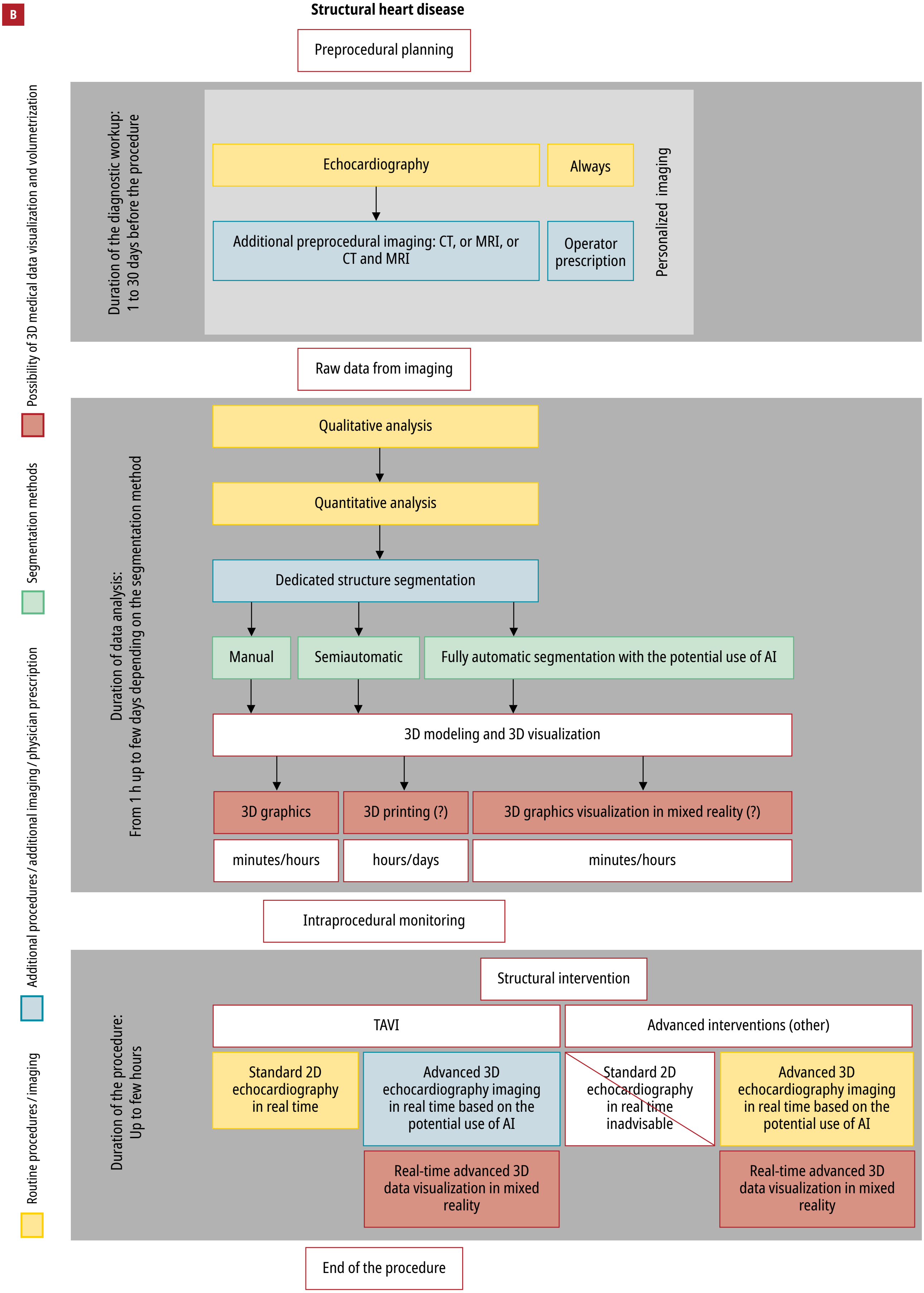


FIGURE 1 Flow chart demonstrating how emerging advanced imaging technologies can be integrated alongside contemporary imaging techniques for preprocedural planning and intraprocedural monitoring of percutaneous coronary interventions (**A**) and percutaneous structural interventions (**B**)
Abbreviations: CT, computed tomography; FFR, fractional flow reserve; IVUS, intravascular ultrasound; MRI, magnetic resonance imaging;



NIRS, near-infrared spectroscopy; SPECT, single-photon emission computed tomography; OCT, optical coherence tomography; PET, positron emission tomography; QCA, quantitative coronary analysis; TAVI, transcatheter aortic valve implantation; 3D, 3-dimensional; 2D, 2-dimensional

Intraprocedurally, the 3D reconstructed images derived from either real-time standard / rotational angiography, or echocardiography, or preprocedural CT or MRI scans can be visualized and projected directly onto the operators' field of vision. Furthermore, these images can be manipulated and analyzed independently by the interventionist, which provides an additional and more flexible source of imaging guidance during complex coronary or structural interventions.[1] Specific image visualization in a 3D-simulated environment provides the operator with better depth perception, whilst providing additional volumetric measurements and data.[2]

At present, mixed reality imaging is an emerging technology, with limited experience and is still the subject of ongoing research. Mixed reality technologies are being introduced into preprocedural planning or intraprocedural monitoring protocols.

Novel imaging-based methods to plan and monitor coronary and structural interventions Currently, imaging technologies are utilized for the diagnosis, classification and preprocedural planning of subsequent percutaneous and surgical interventions. Imaging technologies also play a vital role in the intraprocedural monitoring of interventions, and can lead to improvements in procedural success and safety whilst potentially improving procedural time and cost. Mixed reality imaging is one example of many other emerging advanced imaging technologies.[3] The specific attributes of each technology vary considerably with certain technologies being more advantageous in specific clinical settings. With the increasing number of available options, it is important to select the right imaging technique for the right patient at the right time.

Therefore, we propose a novel imaging approach to procedural planning and monitoring, combining advanced imaging technologies such as mixed reality, 3D segmentation, and 3D printing to improve the planning and performance of coronary and structural interventions (FIGURE 1A and 1B).

Statistical analysis No statistical analysis was performed. Novel imaging-based methods to plan and monitor coronary and structural interventions were proposed as a new concept.

Results and discussion Diagnostic imaging used during treatment planning in patients with coronary artery disease (CAD) can be divided into invasive (angiography, fractional flow reserve [FFR], FFR-based quantitative coronary analysis, intravascular ultrasound [IVUS], IVUS with near-infrared spectroscopy [NIRS], optical coherence tomography [OCT])[4] and noninvasive methods (echocardiography, computed tomography [CT], CT perfusion, positron emission tomography, FFR-based CT, magnetic resonance imaging [MRI], single-photon emission computed tomography).[5] Based on the resulting images, 3D modelling techniques can be used to create and analyze patient-specific models, which may aid the decision-making process, especially when trying to determine the best method of revascularization.

The potential advantages of these methods in the planning for patients with CAD are relatively limited. Currently, FFR is recommended for the assessment of intermediate coronary stenosis. An emerging alternative is CT-FFR which uses high-quality images from cardiac CT scans to create an arterial 3D model to simulate the blood flow. The resulting software can determine the presence and functional significance of a coronary stenosis without an invasive procedure.

Patients referred for percutaneous coronary interventions (PCI) can undergo real-time imaging during the procedure. In all cases, imaging is performed with 2D angiography, with intra-coronary imaging (IVUS, IVUS-NIRS, OCT) utilized at the operator's discretion. An emerging concept is the use of 3D angiography to guide complex interventions and 3D reconstructions of IVUS, IVUS-NIRS, or OCT images to evaluate plaque morphology, vessel remodeling, and stent geometry of implemented stents.[6]

Structural interventions can be more complex and can require more detailed preprocedural imaging to better understand the anatomy, pathology, and surrounding cardiac structures that might be involved during the intervention. Conventionally, preprocedural planning involves baseline transthoracic echocardiography which is then supplemented by additional diagnostic imaging consisting of either transesophageal echocardiography, CT, or MRI methods alone or in combination. Various quantitative and qualitative parameters are then derived from these different imaging modalities.

A further evolution in CT and MRI imaging platforms involves segmentation of selected cardiac structures, which can be performed either manually or semi- or fully-automatically. Further modelling and analysis of these segmentations can then create 3D graphics, which can be visualized or exported onto 3D printing platforms and / or incorporated into MR imaging systems (FIGURE 1A). This innovative approach to interpret medical data offers new opportunities to both evaluate the underlying anatomy and plan and simulate subsequent procedures.[7]

Patients undergoing structural heart interventions are usually monitored with transesophageal ultrasound in a hybrid operating room. The acquired 2D and / or 3D images can then be exported, processed, and analyzed within the mixed reality platforms in real time. These 3D models can then be manipulated at the operators' discretion to provide a seamless interaction between imaging and intervention.

Conclusions Technological advancements have provided the stimulus to develop mixed reality technologies into interventional practice. These technologies can support physicians during preprocedural planning, provide real-time detailed imaging solutions during complex interventions, and offer unique high-fidelity training opportunities for physicians and fellows alike.

SUPPLEMENTARY MATERIAL

Supplementary material is available at www.mp.pl/kardiologiapolska.

ARTICLE INFORMATION

CONFLICT OF INTEREST None declared.

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